Origin of Collectivity in Transport Models

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We developed a systematic method for computing and analyzing the energy-momentum tensor inside transport models. By examining the spatial distribution as well as the time evolution of the energy-momentum tensor, we addressed the question on the origin of collectivity in heavy ion collisions. Events from Relativistic Quantum Molecular Dynamics (RQMD) at RHIC energies (Au+Au at 200GeV/c) were used in the initial study.

For a system with well-defined particle excitations, the relativistic stress tensor[1] is related to the particle distribution functions $f_i(\vec{r}, \vec{p}, t)$ by

$$T^{\mu\nu}(\vec{r}, t) = \sum_i \int \frac{d^3p}{(2\pi)^3} \frac{p^\mu p^\nu}{p^0} f_i(\vec{r}, \vec{p}, t), \quad (1)$$

where p^μ is the four-momentum, and the subscript i denotes particle species. For cascade models, the integral over the phase space becomes a sum over particle momenta. Under Lorentz transformations, $T^{\mu\nu}$ is a second-rank tensor.

We can diagonalize $T^{\mu\nu}$, a 4×4 matrix, by performing a Lorentz boost followed by a rotation. Boosting to the local rest frame, $T^{\mu\nu}$ is reduced to

$$(T^{\mu\nu}) = \begin{pmatrix} \epsilon & 0 \\ 0 & (p^{ij}) \end{pmatrix} \quad (2)$$

where ϵ is the local energy density and the 3×3 matrix p^{ij} is the momentum tensor which can be further diagonalized by a rotation transformation. The diagonalization of p^{ij} is equivalent to finding the three principal momentum axises of the system. The diagonal elements, P_x, P_y, and P_z, are the pressures along the three principal axises.

There are ten independent elements in a symmetric 4×4 matrix. By diagonalizing $T^{\mu\nu}$, we have found ten well-defined physical quantities which completely characterize $T^{\mu\nu}$. In addition to the four diagonal elements, there are three parameters for the local flow velocity and three parameters defining the principal momentum axis.

For a non-equilibrium system, the local pressure can be non-isotropic. We discussed this and other differences to the non-dissipative hydrodynamical models in which the stress tensor is related to the local energy density ϵ and an isotropic pressure P by

$$T^{\mu\nu} = Pg^{\mu\nu} + (\epsilon + P)u^\mu u^\nu \quad (3)$$

where $u^\nu = \gamma(1, \vec{v})$, with $\vec{v}$ the local flow velocity, and $\gamma = 1/\sqrt{1 - v^2}$.

The spatial distribution and the time evolution of $T^{\mu\nu}$ reveal other aspects of the systems. For example, when the system is near equilibrium we can study the effect of viscosity. To quantify the sensitivity of $T^{\mu\nu}$ in distinguishing different physics content, we first tested our method on several well defined systems, such as one fluid with and without collective flow, two fluids, etc. The focus of our study is the relationship between the local energy-momentum tensors and the observables such as stopping, transverse energy, and various types of collective flows. An immediate goal of this study is to identify important observables for the day-one physics at RHIC.

Footnotes and References

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[1] L.D. Landau and E.M. Lifshitz, Fluid Mechanics, p. 505, 2nd ed. Pergamon Press, 1987; Gordon Baym, private communications, 1996.